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# AFTA-WFIRST Coronagraph Instrument Status Report -- SDT

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1/9 2014

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## Outline

- Introduction
- Newly selected architecture description
- Status and next steps
- Summary



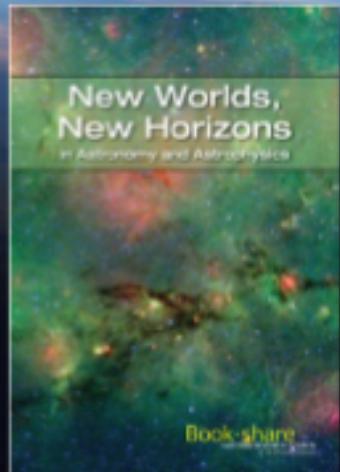
# Exoplanet Missions



Ground-based  
Observatories



2001  
Decadal  
Survey

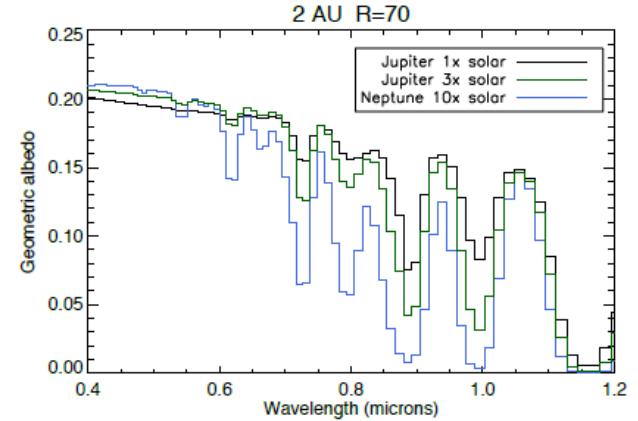
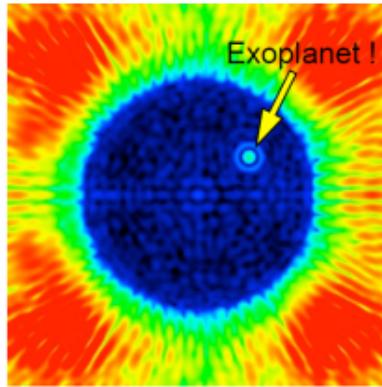


2010  
Decadal  
Survey



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# AFTA Coronagraph Instrument



Coronagraph  
Instrument

Exo-planet  
Direct imaging

Exo-planet  
Spectroscopy

AFTA WFIRST  
Wide-Field Infrared Survey Telescope

Bandpass	430 – 980nm	Measured sequentially in five ~10% bands
Inner working angle	100 – 250 mas	~ $3\lambda/D$ , driven by science
Outer working angle	0.75 – 1.8 arcsec	By 48X48 DM
Detection Limit	Contrast $\leq 10^{-9}$ After post processing)	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extreme stability requirements
Spectral Resolution	~70	With IFS, R~70 across 600 – 980 nm
IFS Spatial Sampling	17mas	Nyquist for $\lambda \sim 430$ nm

AFTA Coronagraph Instrument will:

- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

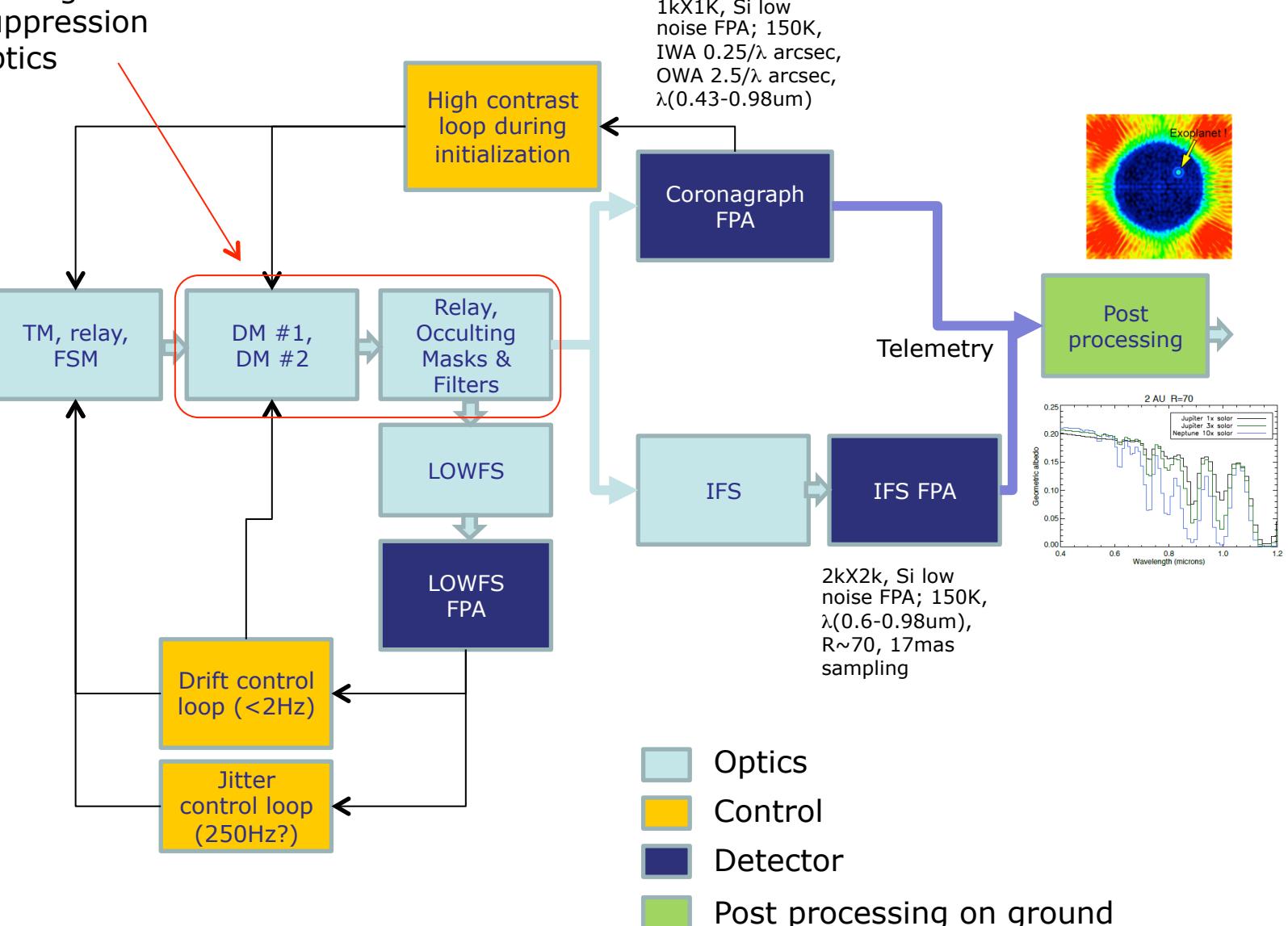


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# Functional Block Diagram



Star light  
suppression  
optics

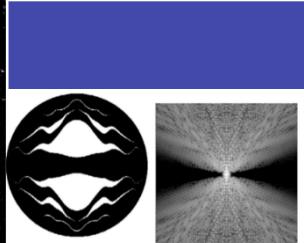




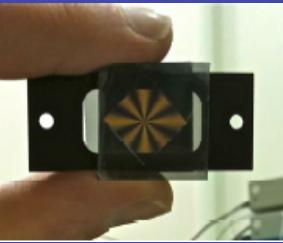
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# Star light suppression -- Technical Approach

## Six different concepts



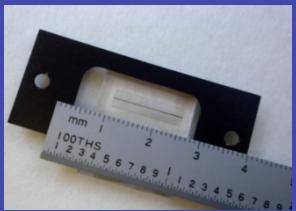
Shaped Pupil Mask Pupil Masking  
(Vanderbei & Kasdin, Princeton Univ.)



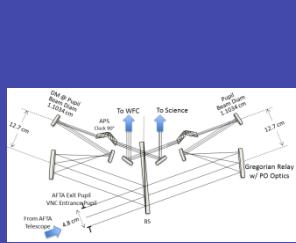
Vector Vortex Mask Image Plane (Serabyn, JPL)



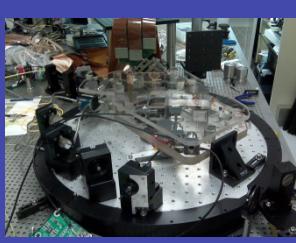
Phase Induced Amplitude Apodization (PIAA)  
Pupil Re-Mapping  
(Guyon, Univ. Arizona)



Hybrid / Band-Limited Lyot Mask  
Image Plane Amplitude & Phase  
(Trauger, JPL)

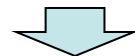


Visible Nuller Coronagraph:  
Phase-Occulting (Lyon, GSFC)

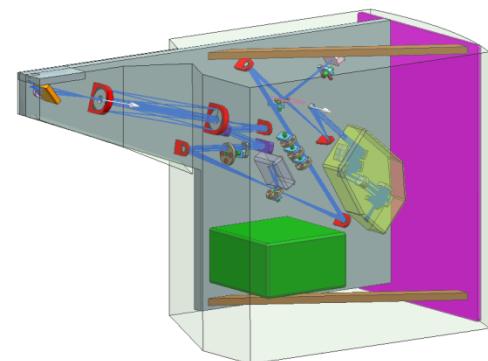
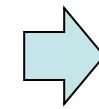
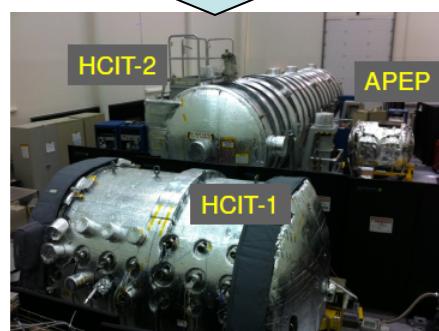


Visible Nuller Coronagraph:  
DaVinci (Shao, JPL)

Down select 12/15/2013  
<http://wfIRST.gsfc.nasa.gov/>

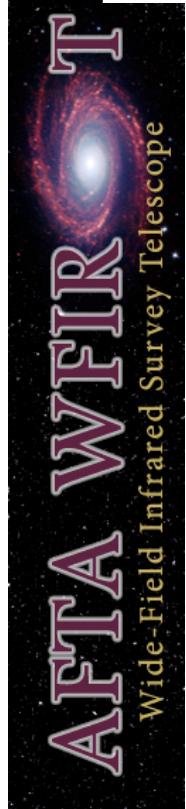


Primary Architecture (OMC)	Back-up Architecture (PIAACMC)
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TRL-5 @ start of Phase A (10/2016)

TRL-6 @ PDR (10/2018)

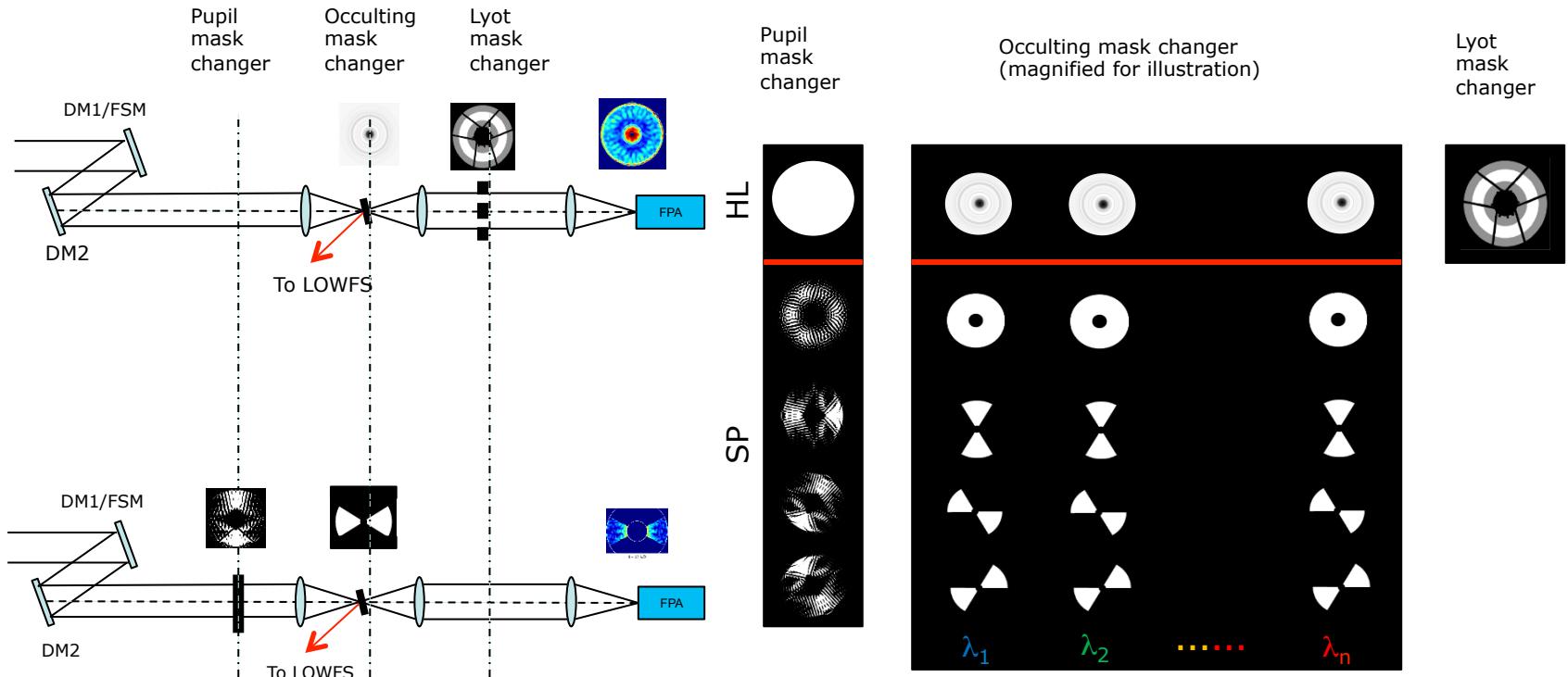




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## Primary Architecture: Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot

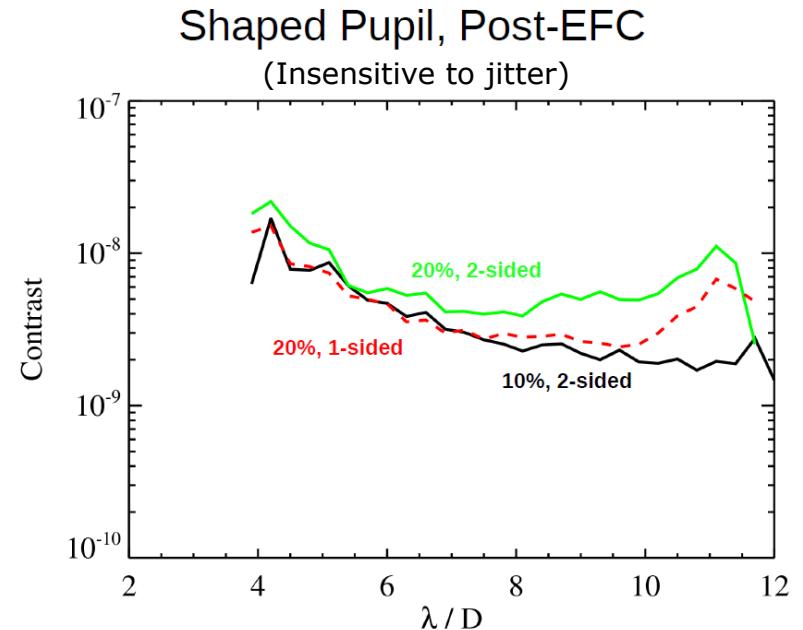
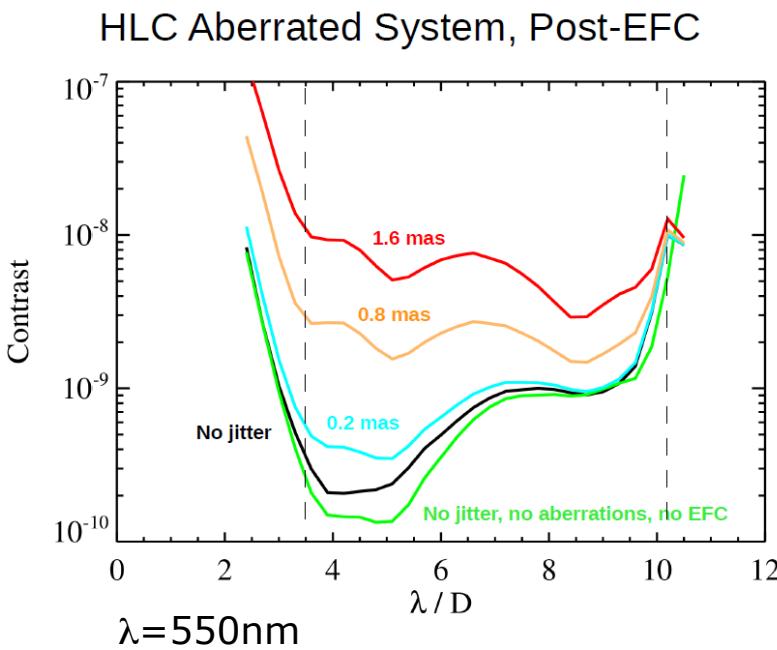
- SP and HL masks share very similar optical layouts
- Small increase in over all complexity compared with single mask implementation





## Contrast simulations with AFTA pupil, aberrations and expected range of telescope pointing jitter

- OMC in its “SP mode” provides the simplest design, lowest risk, easiest technology maturation, most benign set of requirements on the spacecraft and “use-as-is” telescope. This translates to low cost/schedule risk and a design that has a high probability to pass thru the CATE process.
- In its “HL mode”, the OMC affords the potential for greater science, taking advantage of good thermal stability in GEO and low telescope jitter for most of the RAW speed



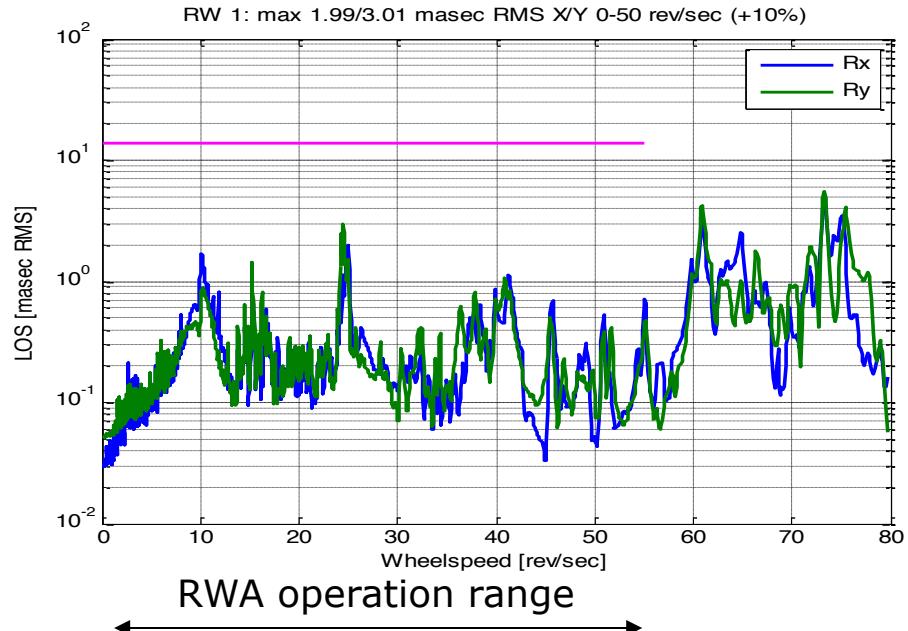
Good balance of science yield and engineering risk



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## Observatory Pointing Jitter Estimate

- The results indicate telescope LOS jitter less than 1 mas over a wide range of wheel speeds, before LOWFS tip/tilt correction.
  - Except at wheel speed ~10 and 26 rps
- Numerous opportunities exist for further jitter optimization:
  - operational constraints,
  - momentum management strategies,
  - structural redesign,
  - LOWFS design optimization



“Model uncertainty factor (MUF)”  
consistent with flight projects  
(MUF=2.5 for  $f < 20\text{Hz}$ , and MUF=6 for  
 $f > 40\text{Hz}$ , linear in between)

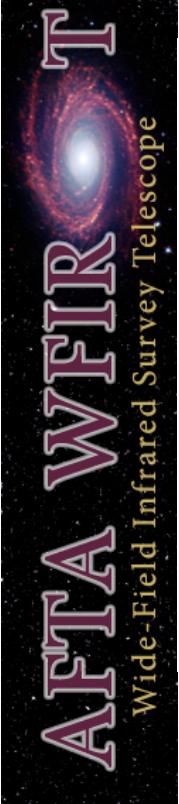
AFTA WFIR  
Wide-Field Infrared Survey Telescope



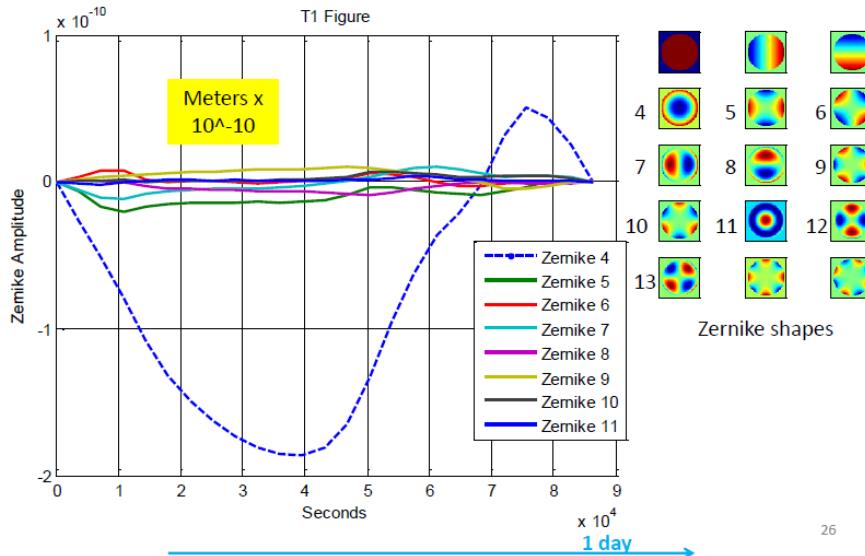
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# Telescope Thermal Stability Estimate

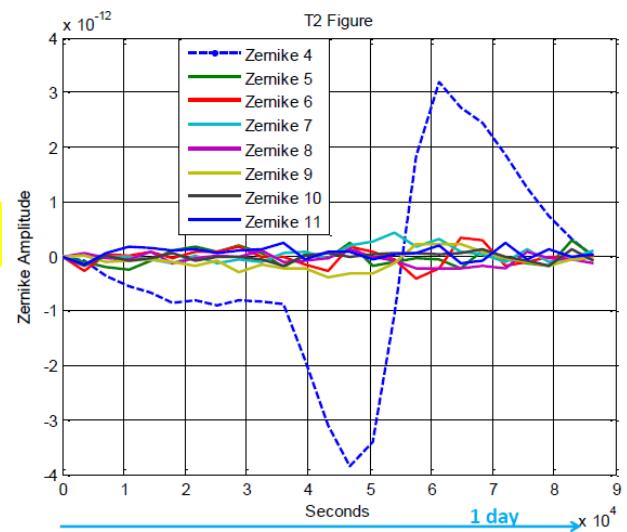
- Recent STOP model results indicate very stable telescope wavefront during operation
  - Dominant term is focus, ~2nm over 24 hrs
  - Other low-order WFE <20pm over 24 hrs



T1 Zernike Amplitudes over 24 Hours



T2 Zernike Amplitudes over 24 Hours

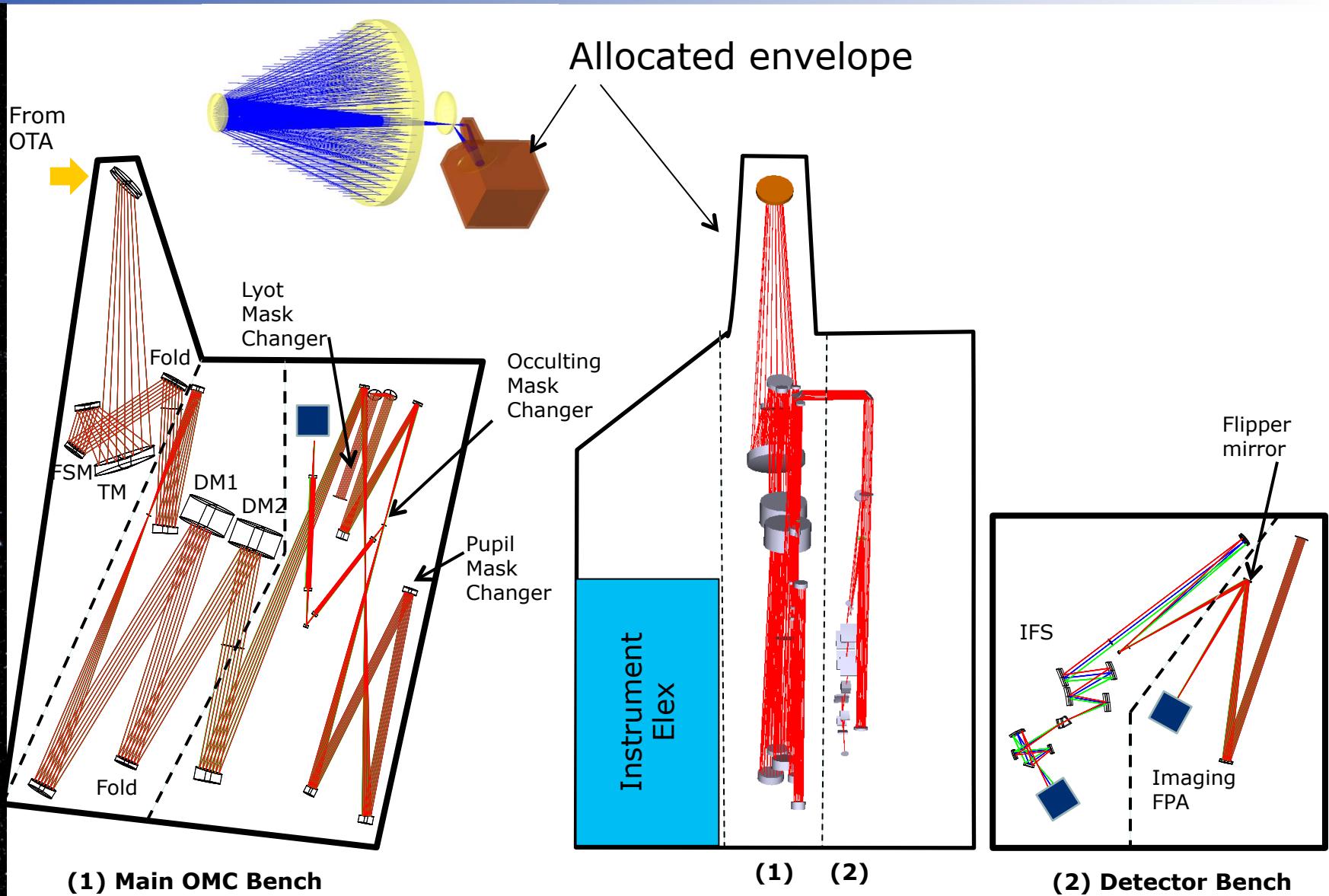


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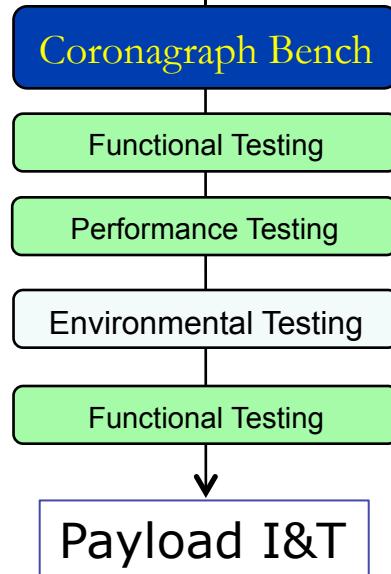
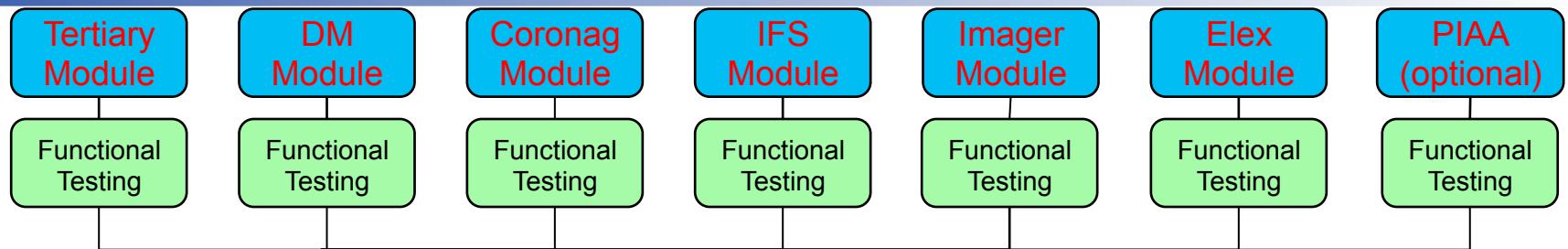
# Instrument Layout within the Allocated Envelope





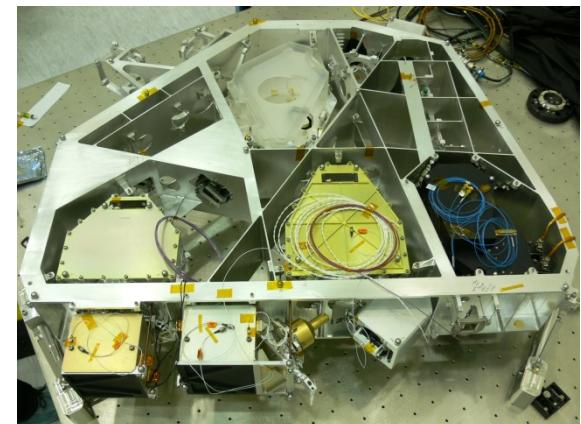
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# Functional Modularized Instrument



## **Modularized Instrument:**

- Simple interface (collimated beam)
- Flexible early EDU risk mitigation
- Shorter flight I&T duration
- Ease of international participation



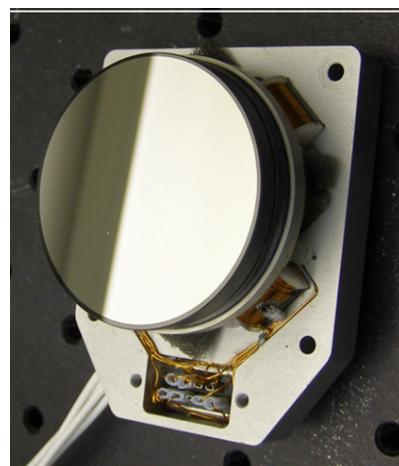
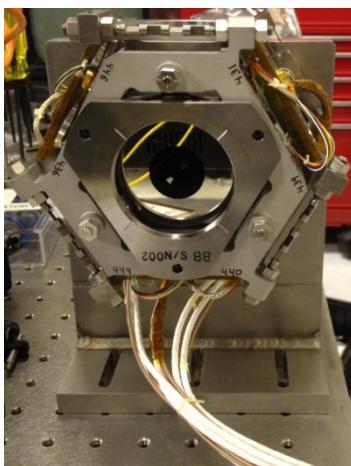
Modularized example (SIM ABC)



## Active Optics

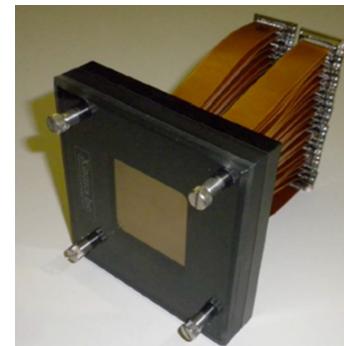
### Fine Steering Mirror (FSM)

- To correct telescope line-of-sight (wavefront tip/tilt) error
- Low risk with rich flight heritage



### Deformable Mirror (DM)

- To correct telescope & instrument optical WFE (static and drift)
- Low risk with good heritage:
  - Flight PMN actuators, driver electronics
  - HCIT contrast demonstration to  $10^{-10}$
  - Assembly passed random vibe test (2012)



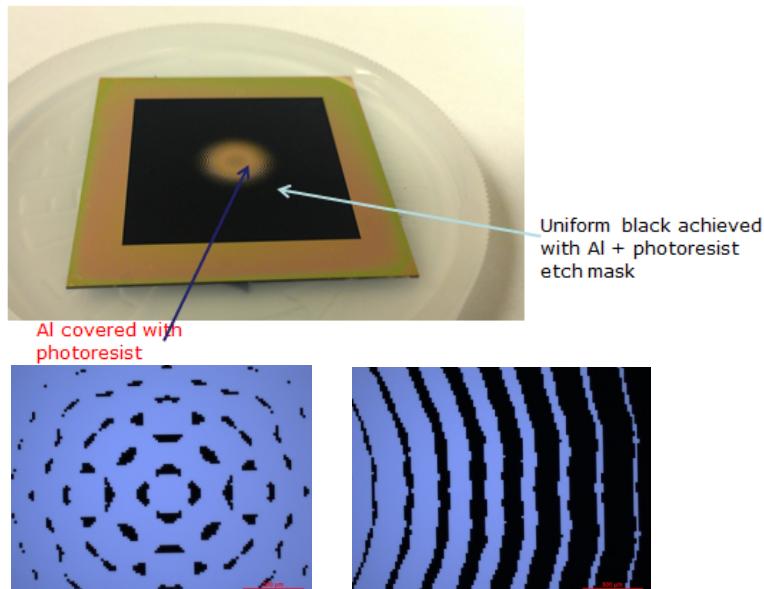
Low risk for flight implementation



## Coronagraph Masks

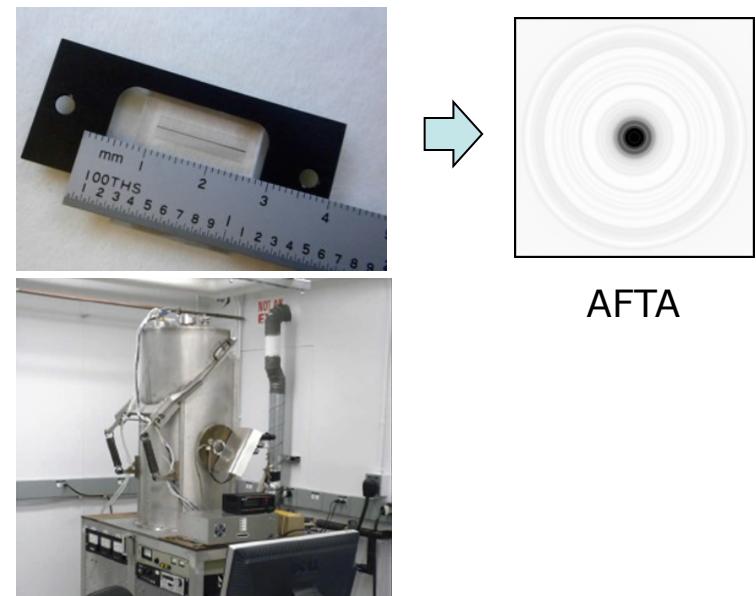
### Reflective shaped pupil masks

- Black Si on Al mirror coating demonstrated at JPL/MDL and Caltech/KNI



### Transmissive hybrid Lyot mask

- Profiled Ni layer (amplitude) over-coated with profiled MgF<sub>2</sub> layer (phase) at JPL Trauger's lab
- Linear mask fabricated and demonstrated 10<sup>-10</sup> in HCIT for un-obscured pupil



Both masks have credible plan for FY14 delivery to HCIT



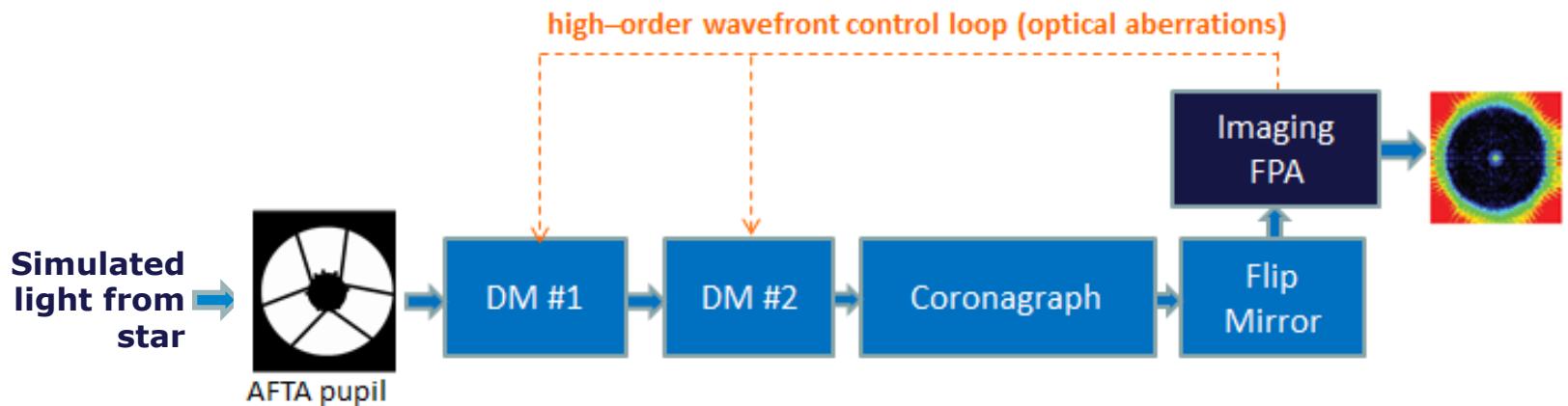
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# System-Level Testbed Demonstration

## Phase 1: Static Wavefront

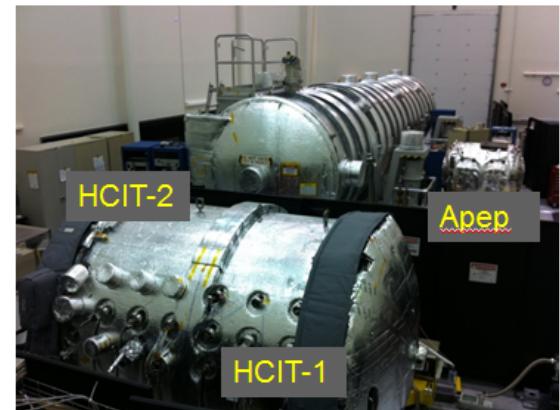
### Possible Path to Closing Gap

Demonstrate static wavefront performance in fully-assembled coronagraph vacuum testbed with simulated AFTA-WFIRST telescope pupil.



### Key Demonstration Objectives

- Coronagraph masks/apodizers for AFTA-WFIRST obscured pupil
- Two-DM configuration
- Wavefront control algorithms developed
- Static wavefront performance:
  - 1e-8 contrast
  - 2% → 10% BW (in 500-600 nm window)





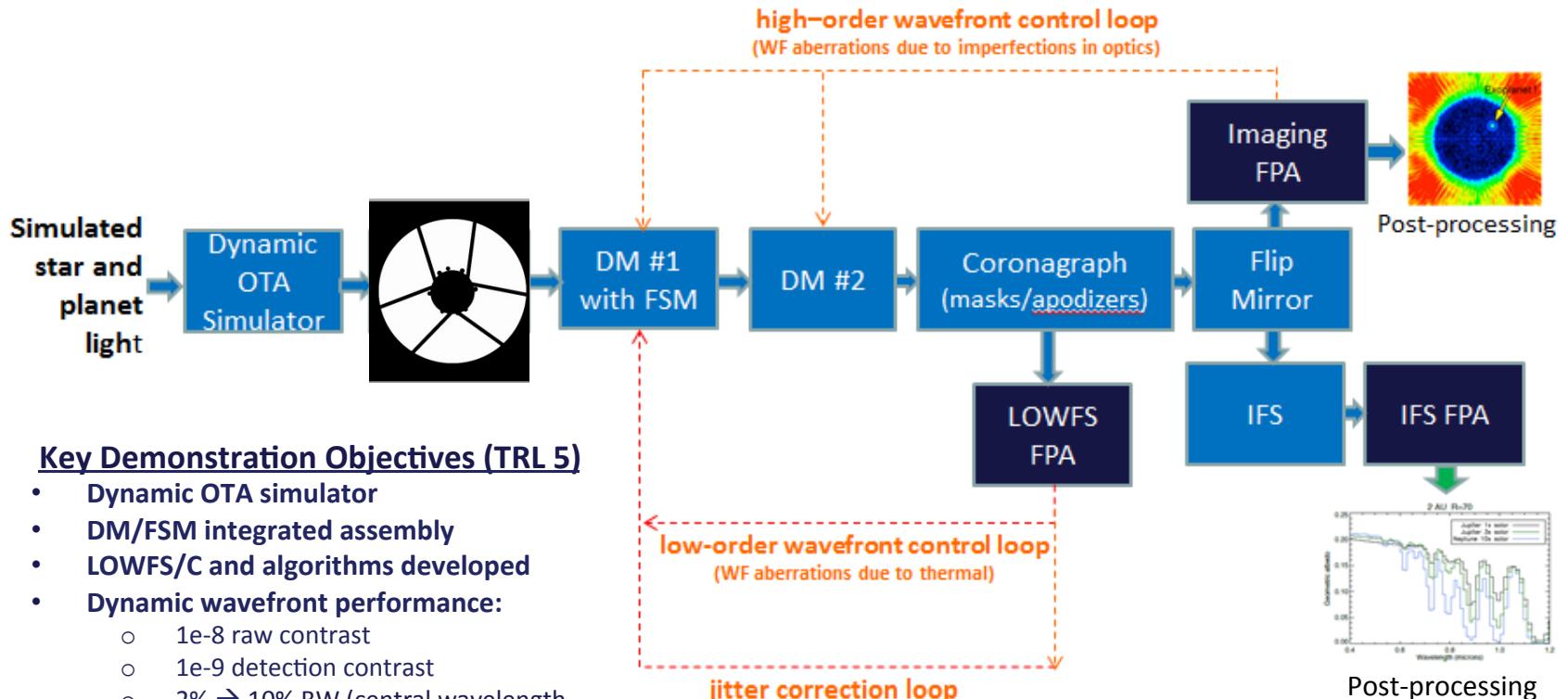
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# System-Level Testbed Demonstration

## Phase 2: Dynamic Wavefront

### Possible Path to Closing Gap

Demonstrate dynamic wavefront performance in fully-assembled coronagraph vacuum testbed with simulated AFTA-WFIRST telescope pupil in a dynamic env't.



#### Key Demonstration Objectives (TRL 5)

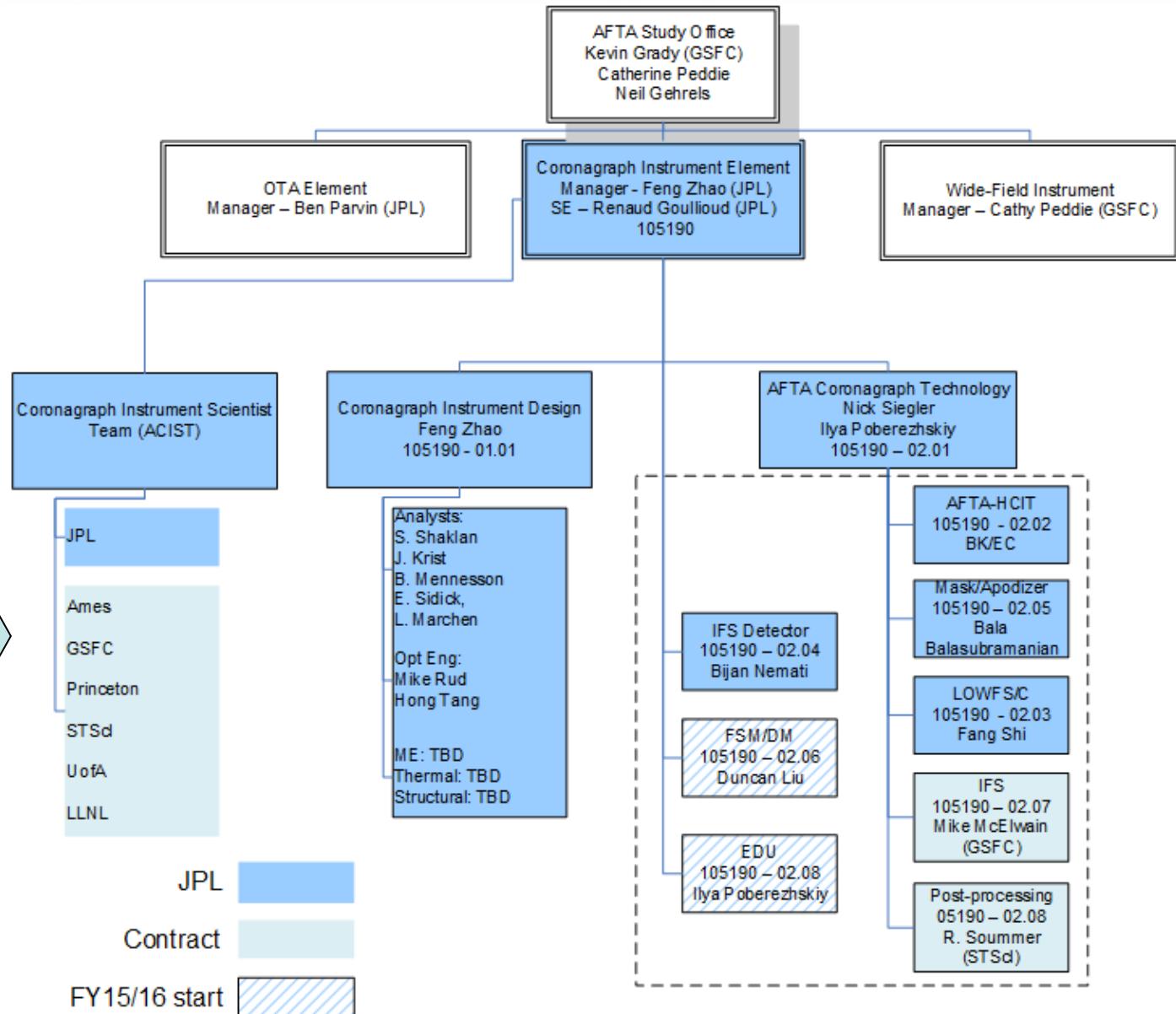
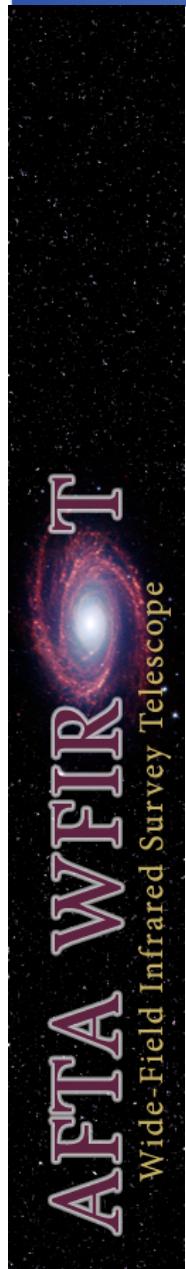
- Dynamic OTA simulator
- DM/FSM integrated assembly
- LOWFS/C and algorithms developed
- Dynamic wavefront performance:
  - 1e-8 raw contrast
  - 1e-9 detection contrast
  - 2% → 10% BW (central wavelength of 550 nm)
  - IFS ( $R \sim 70$  TBD) separately
- Planet simulation and extraction





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# Org Chart





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## Next Steps

- Technology Maturation:
  - Submit technology maturation plan to HQ with milestones FY14-FY16 (TRL-5 demonstration by 10/2016)
- AFTA-WFIRST DRM:
  - SDT interim report 4/2014
  - SDT final report 1/2015
  - CATE 2/2015
- Wider community participation
  - ACIST
  - International partnership

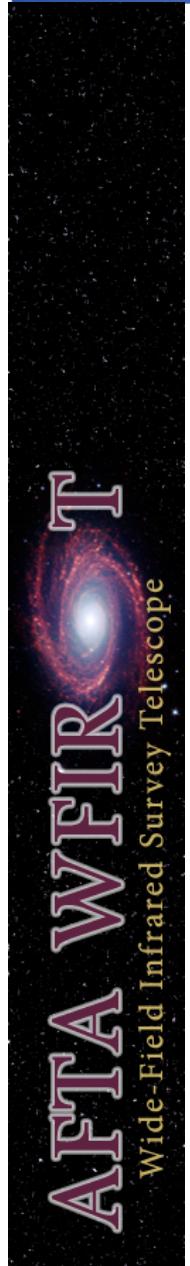




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## Summary

- Exciting coronagraph technology maturation for a generic telescope (such as AFTA)
  - Benefit future exo-Earth imaging missions using a generic telescope (such as ATLAST)
- AFTA-WFIRST Occulting Mask Coronagraph offers balanced science returns and engineering risks
- Strong interest from community and international partners, modularized instrument design offers simple interface and flexible contributions





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## Acknowledgement

- Contributions from team members from JPL, GSFC, Princeton, Univ of Arizona, Ames, LLNL, STScl, Caltech



**JPL**

